Modeling an Asteroid Impact

Did It Kill the Dinosaurs?

by Maureen Oakes

Mounting scientific evidence supports the theory that a large asteroid slammed into Earth about 65 million years ago—killing the dinosaurs and ending the Cretaceous Period. Simulations developed at the Laboratory are providing new insight into this catastrophic event.

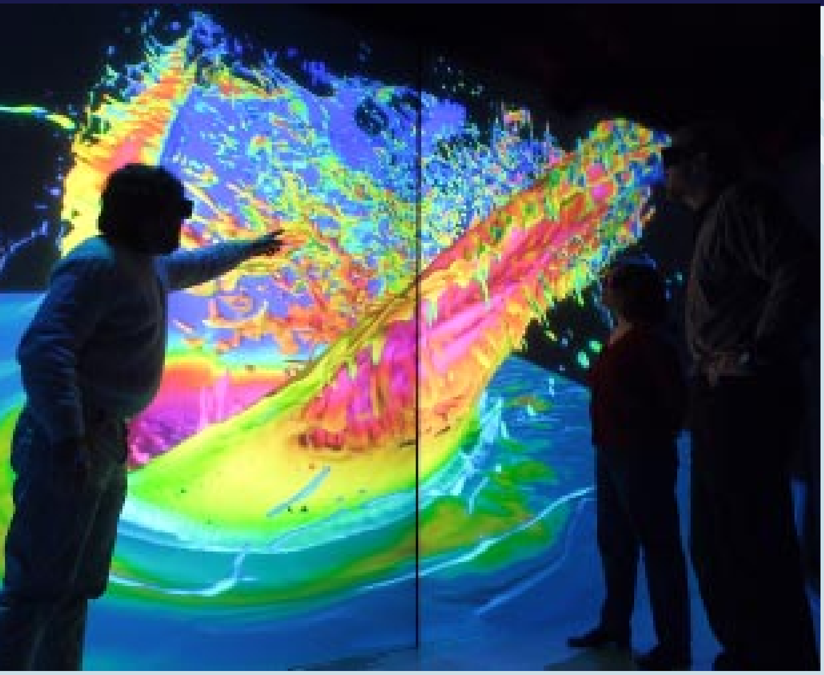
What would happen if a 10-kilometer-diameter asteroid penetrated Earth's crust at a speed of 15 to 20 kilometers per second? The kinetic energy of such an asteroid (more than 6 miles in diameter) would equal the energy of 300 million nuclear weapons and create temperatures hotter than on the sun's surface for several minutes. The expanding fireball of superheated air would immediately wipe out unprotected organisms near the impact and eventually lead to the extinction of many species worldwide.

Immediate effects would include an eardrum-puncturing sonic boom, intense blinding light, severe radiation burns, a crushing blast wave, lethal balls of hot glass, winds with speeds of hundreds of kilometers per hour, and flash fires. Longer-term effects would alter Earth's climate.

Courtesy of Smithsonian Institution

Triceratops, a plant-eating dinosaur that lived during the late Cretaceous Period.

The vapor and debris thrust into the stratosphere would block sunlight for months, lowering global temperatures.



John Flower

Researcher Galen Gisler (left) points out features of the debris curtain formed in a simulation of the Chicxulub asteroid impact. The complex computation for the simulation ran on a section of the Q machine—the new supercomputer in the Nicholas C. Metropolis Center for Modeling and Simulation. Completing the calculations required one million computing hours.

Organisms that could not adapt to this impact version of a "nuclear winter" would die. Since plants derive energy from the sun, they would be affected first. As plants die, the decreased food supply and oxygen levels would affect the herbivores first, followed by the carnivores and on up the food chain. Birds, fish, mammals, and small reptiles could survive the cold, desolate "winter" if they could burrow underground or live in caves and consume alternate food sources such as seeds, roots, and decaying matter. Most large reptiles would perish.

3-D Simulation

After the discovery of the Chicxulub crater at the tip of Mexico's Yucatan Peninsula, scientists began developing numerical models to understand the sequence of events during the impact and their consequences. The rapidly increasing power of supercomputers and sophistication of simulations facilitated this research.

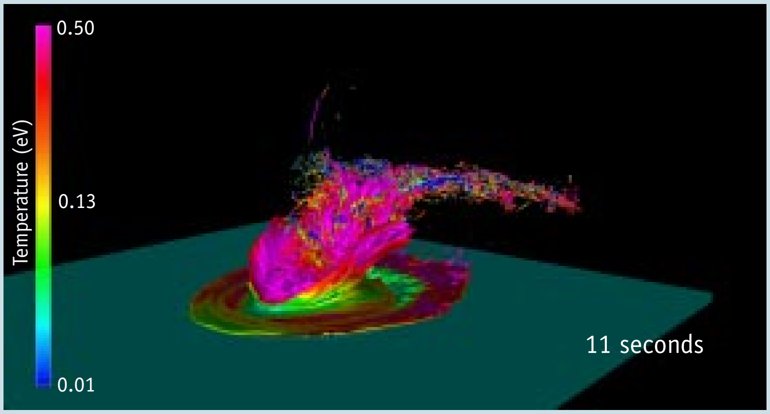
A team from the Applied Physics Division recently announced the results of a three-dimensional (3-D) simulation created with codes developed at Los Alamos. Galen Gisler, Bob Weaver, and Charles Mader, working with Michael Gittings of Science Applications International Corporation, have generated a dynamic picture of the asteroid impact. They collaborated with Jay Melosh and a research team from the University of Arizona, who offered advice on the simulation physics and parameters.

Their model focuses on the early-time effects: when the asteroid plunges through Earth's atmosphere and into water and layers of calcite, granite, and mantle. Craters are formed by the explosion of vaporized rock produced as the asteroid's kinetic energy is dissipated through contact with Earth's surface. Steeper impacts result in deeper penetration, but shallower impacts produce larger craters.

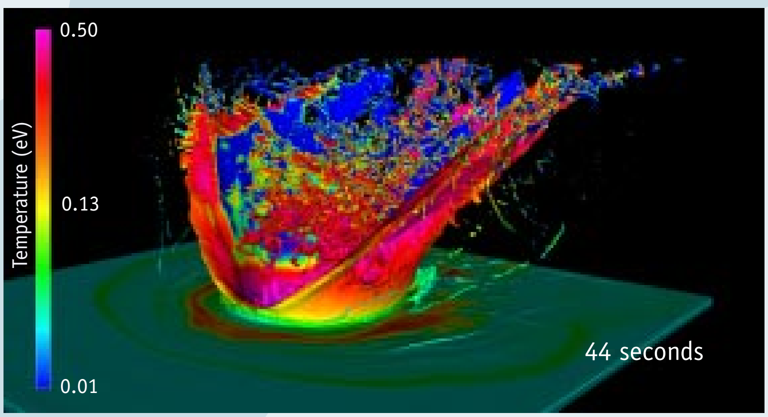
To understand the importance of the impact angle, Gisler simulated three different angles: 30, 45, and 60 degrees. He discovered that a lower angle of impact is much more efficient at focusing thermal energy into the troposphere, where Earth's weather occurs. "I wasn't smart enough to know this before the simulation," said Gisler. This focusing occurs mainly downrange, carrying the horizontal momentum of the asteroid. Thus, if the Chicxulub asteroid arrived at a low impact angle from a southerly direction, it could have set fire to all the forests in North America. Indeed, soot deposits are found in the continent's iridium layer, formed 65 million years ago (see What Killed the Dinosaurs?).

This simulation builds on Gisler's earlier work in modeling giant impact-generated tidal waves, called tsunamis. He and his co-workers completed the largest and most accurate 3-D models of tsunamis caused by asteroids. They simulated six asteroids of varying sizes crashing into the ocean at a speed of 20 kilometers per second. The simulations have potential value in planning emergency response to the huge waves.

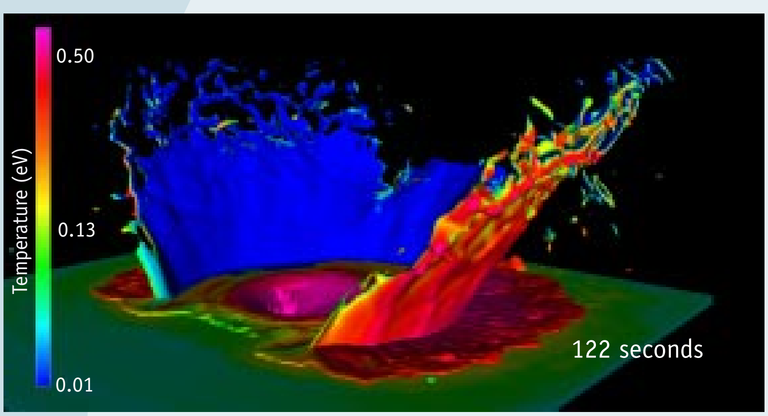
Simulating the Chicxulub Asteroid Impact



A few seconds after the 10-kilometer-diameter asteroid strikes Earth, billions of tons of very hot debris are lofted into the atmosphere. Much of the debris is directed downrange (to the right and back of the image), carrying the horizontal momentum of the asteroid in this 45-degree impact. The asteroid plunges into 300 meters of water that overlies 3 kilometers of calcite, 30 kilometers of granite, and mantle material—layers that correspond to those of the Chicxulub impact site in the late Cretaceous Period. At that time, the Yucatan Peninsula was on the continental shelf, which consisted mainly of fossilized coral reefs. This image is a perspective rendering of a density isosurface colored by the temperature of materials (0.5 eV = 10,000°F). The scale is set by the back boundary, which is 256 kilometers long; the height of the debris' "rooster tail" is 50 kilometers.



Less than a minute after impact, the rooster tail has moved far downrange, out of the simulation. The dissipation of the asteroid's kinetic energy produces a stupendous explosion that melts, vaporizes, and ejects a substantial volume of calcite, granite, and water. The dominant feature here is the conical "curtain" of hot debris that has been ejected and is now falling back to Earth. The turbulent material inside this curtain is still being accelerated by the explosion from the crater's excavation.



Two minutes after impact, the debris curtain has separated from the rim of the still-forming crater as debris in the curtain falls to Earth. The debris is deposited asymmetrically around the crater, with more falling downrange than uprange. The distribution of material in the ejecta can be used to determine the direction and angle of impact of the asteroid. Cores that have been obtained around the Chicxulub impact site are consistent with a southerly direction for the impact. Future drilling—guided by simulations such as these—may help to determine more definitively the geometry of impact.

Beyond Dinosaurs

Scientists around the globe are keeping an eye on the sky. NASA has a Near-Earth Objects program that tracks asteroids. Two of the many projects sponsored by the program are the Lowell Observatory Near-Earth Object Search near Flagstaff, Arizona, and the Lincoln Near-Earth Asteroid Research near Socorro, New Mexico. These observatories have identified and obtained orbital parameters for an estimated 90 percent of all asteroids in the solar system larger than 1 kilometer in diameter. In Vienna, the International Monitoring System is tuned to detect sound waves created by exploding meteors in the atmosphere—about thirty per year—with frequencies too low to be audible to the human ear. Some of these meteors are as small as basketballs.

An asteroid impact on land could cause vast forest fires such as the famous Tunguska event of 1908, when such an impact devastated 2,000 square kilometers of Siberian forest. It could also cause global climate changes, possibly severe enough to destroy civilization. A marine impact could generate a tsunami capable of inundating the coasts on both sides of the ocean.

Destructive impacts such as Tunguska are likely to happen but once every thousand years. And there is only a 1 in 200,000 chance that a 1-kilometer-diameter asteroid will hit Earth in a given year. Still, scientists do not want to be caught off guard. They would like to be able to identify risks, predict the occurrence of significant impacts, prepare for future impacts, and even mitigate the effects of an impact. Gisler and his team are contributing to this research. ■

What Killed the Dinosaurs?

In 1980, father and son Louis and Walter Alvarez from the University of California went on a geology expedition in Italy. Their mission: to investigate the layer in Earth's crust that marks the end of the Cretaceous Period. They discovered that the layer contains an unusually high level of iridium, an element that is rare on Earth but abundant in asteroids. Later investigation revealed that the iridium in this layer extends worldwide. The duo hypothesized that its global presence resulted from a giant asteroid striking Earth. Furthermore, they suggested that a series of events after the impact was responsible for a major biological catastrophe—the extinction of more than 50 percent of Earth's plant and animal species, including the dinosaurs.

NASA

A radar image of the southwest portion of the buried Chicxulub impact crater.

The search to find the impact crater then began, with scientists using technology such as seismic-monitoring equipment designed for oil exploration. Several years later, Pemex, the national Mexican oil drilling company, discovered a huge crater at the tip of the Yucatan Peninsula, near the village of Chicxulub. Hidden under a thick layer of sediment deposited over the past 65 million years, the crater lies partly on land and partly under the ocean. It is some 170 kilometers in diameter, or more than 100 miles across.

The Researcher

John Flower

Galen Gisler received a B.S. in physics from Yale University and a Ph.D. in astrophysics from the University of Cambridge. He has been at Los Alamos since 1981. Before studying asteroid impacts, he worked in the fields of astrophysics, plasma physics, adaptive processing, and astronomical transients.